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AN EXPERIMENTAL INVESTIGATION ON POTENTIAL USE OF RECYCLED COARSE AGGREGATES FROM CONSTRUCTION DEMOLITION WASTE AS PARTIAL REPLACEMENT IN CONCRETE

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ABSTRACT

The rapid growth of the construction industry has led to an increase in construction demolition waste (CDW), posing a significant environmental challenge. This study explores the potential of untreated recycled coarse aggregates (RCA) from CDW in concrete production, focusing on the hardened properties of concrete. RCA is systematically integrated into concrete mixes at varying proportions, and critical parameters like compressive strength, split tensile strength and flexural strength are evaluated for M30-grade concrete. Moreover, microstructural study such as scanning electron microscopy (SEM) was also conducted, which provide insight into the mechanisms and structural changes induced by the use of RCA. The experimental results reveal a nuanced relationship between RCA content and concrete's mechanical properties. Compressive strength declines gradually with increased RCA content, while split tensile and flexural strengths exhibit complex trends driven by RCA properties and the concrete matrix. SEM uncovers the interfacial transition zone between RCA and the cement matrix, elucidating bond characteristics and potential weaknesses. EDX sheds light on the elemental composition of concrete phases, revealing chemical interactions between RCA and cementitious materials.

Keywords: Construction Demolition Waste, Concrete, Microstructural Study, Scanning Electron Microscopy.

I. INTRODUCTION

In the realm of civil engineering and construction materials science, the sustainability and environmental impact of construction practices have garnered ever-increasing attention over the past few decades. One pivotal facet of this ongoing discourse is the effective management of construction demolition waste, a resource that, if harnessed judiciously, can contribute to significant reductions in environmental degradation and resource depletion. The process of recycling and reusing construction debris, particularly in concrete production, presents a multifaceted avenue for mitigating the industry's ecological footprint. This paper delves into the territory of utilizing untreated recycled coarse aggregates, extracted from construction demolition waste, as a prime ingredient in concrete formulation. The burgeoning demand for sustainable construction practices, combined with the finite supply of natural aggregates, underscores the importance of exploring alternative sources and solutions. In this context, the primary objective of this study is to assess the mechanical parameters of concrete fabricated with these recycled coarse aggregates, thereby contributing valuable insights into the feasibility of their incorporation in construction materials. The decision to investigate untreated recycled coarse aggregates is particularly significant due to their distinctive characteristics, which differ markedly from their conventionally sourced counterparts. These recycled aggregates exhibit varying degrees of contamination, surface roughness, and potential for weak interfacial bonding with the cement matrix. Hence, an in-depth analysis of their mechanical performance is vital to elucidate the challenges and opportunities they present for the construction industry. The mechanical parameters to be explored in this study encompass compressive strength, flexural strength and split tensile strength. These parameters are pivotal in assessing the suitability of recycled coarse aggregates for structural applications, and their determination will involve rigorous testing procedures, quality control measures, and statistical analysis. Furthermore, the microstructural analysis conducted in this study employs advanced techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), to delve into the intricate interplay between the untreated recycled coarse aggregates and the cementitious matrix. Through this, the study aims to uncover the underlying mechanisms influencing the performance and structural integrity of concrete containing recycled aggregates, thereby contributing to the knowledge base of sustainable construction materials.

II. METHODOLOGY

The project methodology encompasses the following steps:

Sample Collection and Preparation

This phase involves the gathering of construction demolition waste from the demolition site, subsequently subjecting it to processing through hammers and a jaw crusher to acquire recycled coarse aggregates.

Performing Physical Tests on Materials

Comprehensive physical assessments are conducted on all materials used for concrete preparation in accordance with the guidelines stipulated by various IS codes.

Mix Design and Sample Preparation

The concrete mix proportions are determined for achieving M30 grade, following the specifications outlined in IS 10262:2019. Samples are prepared, integrating different percentages of RCA (0%, 25%, 50%, 75% and 100%) in lieu of natural coarse aggregates.

Mechanical Testing

Evaluations encompass both fresh and hardened concrete to ascertain workability and a spectrum of mechanical parameters such as compressive strength, split tensile strength, and flexural strength, adhering to IS codes. Comparative analysis is performed with respect to the control mix concrete, which represents conventional concrete.

Materials Used

Cement

The project employed Ordinary Portland Cement (OPC) conforming to grade 43 as specified by IS 8112-2013 as the cementitious binder. Table-1 presents the tested physical parameters and their corresponding results.

Table-1 Properties of cement used.

Properties	Obtained Values
Fineness (in %)	4.67
Consistency (in %)	28
Initial Setting Time (IST) (in minutes)	78
Final Setting Time (FST) (in minutes)	393

Natural Coarse Aggregates

Coarse aggregate refers to the portion of the concrete mix that is composed of large particles, typically greater than 4.75 mm in diameter. It includes materials such as gravel, crushed stone etc., which provide structural stability and strength to the concrete mixture. Coarse aggregate used are in accordance to IS: 383-1970 and results obtained by performing various physical test are described in Table-2.

Table-2 Properties of NCA used.

Physical Properties	Values
Nominal size (in mm)	20
Aggregate impact Value (in %)	16.76
Specific gravity	2.65
Water absorption (in %)	0.45

Natural Fine Aggregate

Fine aggregate refers to the small-sized granular material, typically passing through a 4.75 mm sieve, that is commonly used in the production of concrete and mortar. It plays a crucial role in providing workability, cohesiveness, and filling voids in the mixture, contributing to the overall strength and durability of the concrete.

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Fine aggregate used for the project are in accordance to IS: 383-1970 and Table-3 illustrates the various physical parameters tested.

Table-3 Properties of NFA used.

Physical Properties	Values
Zone	I
Specific gravity	2.64
Water absorption (in %)	1.11

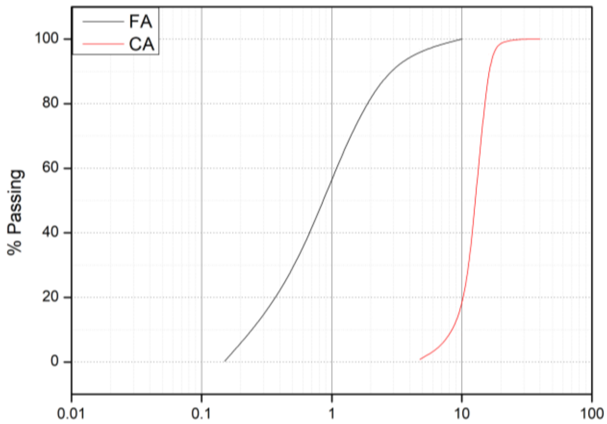

Fig-1 Gradation chart of NCA and NFA.

Recycled coarse aggregate

Recycled coarse aggregate refers to crushed stone, gravel, or similar construction material that has been recovered from demolished or discarded structures and processed for reuse in new construction projects, providing a sustainable alternative to traditional natural coarse aggregates. RCA used are in accordance to IS: 383-1970 and Table-4 illustrates results obtained by conducting various physical test on RCA.

Table-4 Physical properties of RCA.

Physical Properties	Values
Nominal size (in mm)	20
Aggregate impact Value (in %)	24.83
Specific gravity	2.52
Water absorption (in %)	2.875

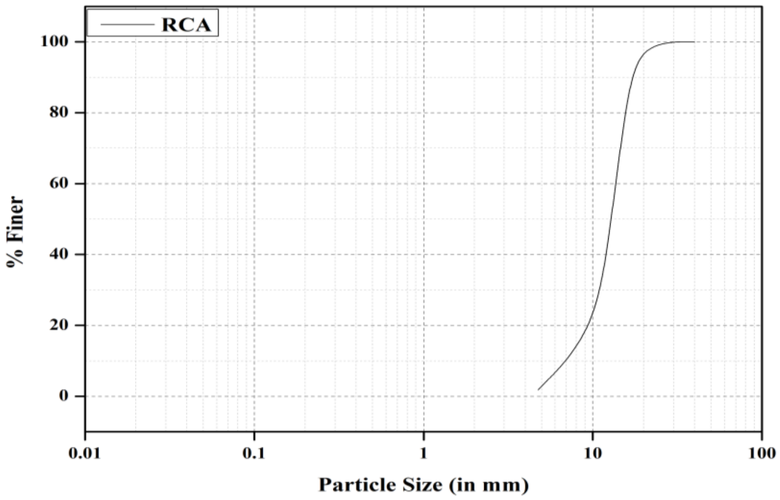

Fig.2- Gradation chart of RCA.

Superplasticizer

FOSROC CONPLAST SP430G8 superplasticizer, based on sulphonated naphthalene polymers was used for the study and various properties of superplasticizer used are listed in Table 5 below.

Table 5- Properties of superplasticizer used.

Properties	Values
Specific Gravity	1.24-1.26
Chloride Content	Nil
Air entrainment	Approx. 1%

Mix Design

Mix proportioning of concrete was done as per IS 10262-2019. Table-6 illustrate the mix design of M30 grade concrete.

Table 6- Mix design of M30 grade concrete.

Materials	Quantity (in kg/m^3)
Cement	366.81
Fine Aggregate	746.16
Coarse Aggregate	1178.02
Water	157.73
Admixture	3.3

Sample Preparation

Following mix design preparation, multiple concrete samples were prepared in compliance with different IS codes for the assessment of concrete's mechanical properties. Specifically, 150mm cubes were fabricated according to IS 516:1959 for the assessment of compressive strength, while 100mm diameter, 200mm length cylinders were prepared in adherence to IS 5816:1999 to determine split tensile strength. Additionally, 150mm x 150mm x 700mm beams were constructed in accordance with IS 516:1959 to evaluate concrete's flexural strength. Table 7 illustrates the nomenclature of samples prepared for project.

Table 7- Nomenclature of samples prepared.

Natural Coarse Aggregate (In %)	Recycled Coarse Aggregate (In %)	Natural Fine Aggregate (In %)	Nomenclature
100	0	100	CWRCA -1
75	25	100	CWRCA -2
50	50	100	CWRCA -3
25	75	100	CWRCA -4
0	100	100	CWRCA -5

III. RESULTS AND DISCUSSIONS

Compressive Strength of concrete

The compressive strength analysis of concrete cubes was conducted at 7, 14, and 28-day intervals during the curing process, with the results compared against the standard CWRCA-1 (conventional concrete). CWRCA-1 exhibited strengths of 33.07 MPa, 42.67 MPa, and 45.13 MPa after 7, 14, and 28 days respectively. Conversely, CWRCA-2 demonstrated a reduction in strength by 5.71%, 10.15%, and 9.26% over the same duration when contrasted with CWRA-1. Similarly, CWRCA-3 displayed a decline in strength by 13.27%, 17.37%, and 14.31% during the identical curing period. The downward trend persisted, with CWRCA-4 showing a weakening of strength by 31.63%, 21.09%, and 22.14% over the same period. Finally, CWRCA-5 showcased a reduction in strength by 37.49%, 44.95%, and 40.04% in comparison to CWRCA-1. Fig shows the compressive strength of concrete for different design mixes.

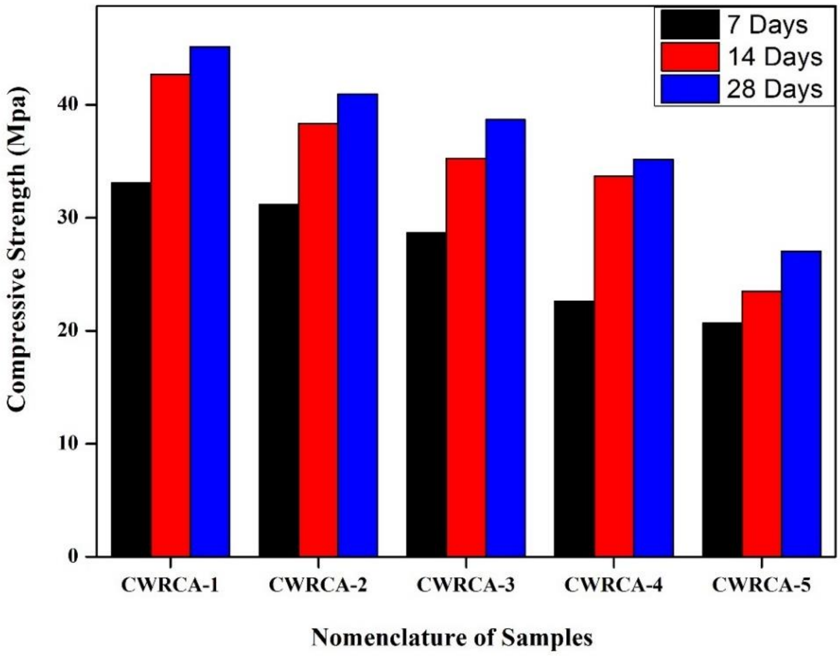

Fig.3- Compressive strength of concrete with RCA.

Split Tensile Strength of concrete

The split tensile strength analysis of concrete cylinders was conducted at intervals of 7, 14, and 28 days after the curing process. The obtained results were then compared with the standard reference material, CWRCA-1. The tensile strength values for the conventional concrete were measured as 3.10 MPa, 3.94 MPa, and 4.92 MPa, respectively, for the corresponding curing periods. Relative to CWRCA-1, it was observed that CWRCA-2 exhibited a strength reduction of 8.38%, 15.99%, and 10.65% for the same curing periods. The tensile strength of CWRCA-3 demonstrated a decline of 15.48%, 22.59%, and 15.74% for identical curing durations. Similarly, the split tensile strength of CWRCA-4 showcased a decline of 33.55%, 26.14%, and 23.38% over the same curing period. Notably, the observed decline in the tensile strength of CWRCA-5 was 39.35%, 47.46%, and 40.97%, respectively, when compared to the reference material, CWRCA-1.

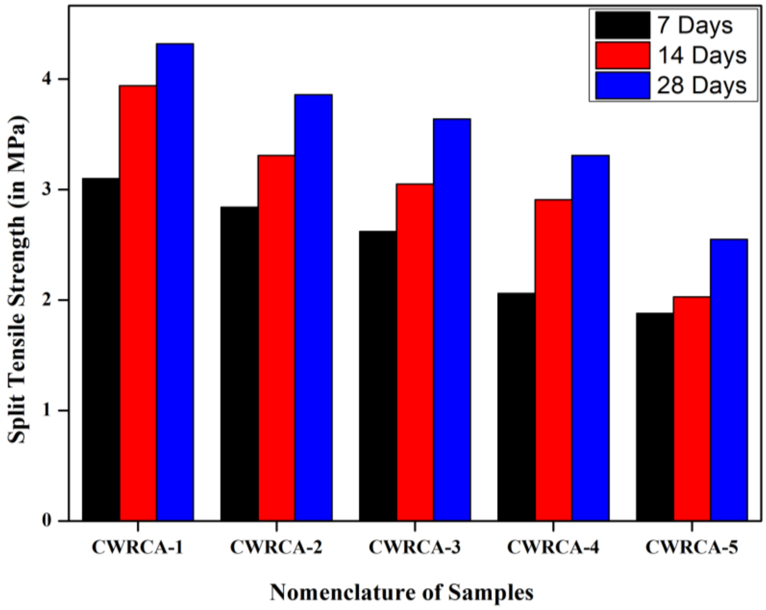

Fig.4- Split Tensile strength of concrete with RCA

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Flexural Strength of concrete

The flexural strength analysis of the concrete beam was conducted at the 7-day and 28-day curing stages, with results subsequently compared against the CWRCA-1 benchmark. CWRCA-1 demonstrated strengths of 4.10 MPa and 4.95 MPa during the corresponding periods. At a 25% replacement level (CWRCA-2), the strength exhibited a decline of 2.92% and 4.84% for the identical curing period. Similarly, concrete subjected to 50% replacement (CWRCA-3) manifested reductions of 7.07% and 7.47%. Notably, CWRCA-4 displayed a reduction in strength of 17.32% and 11.72%. Lastly, CWRCA-5 exhibited a decline of 20.98% and 22.63% compared to the benchmark CWRCA-1.

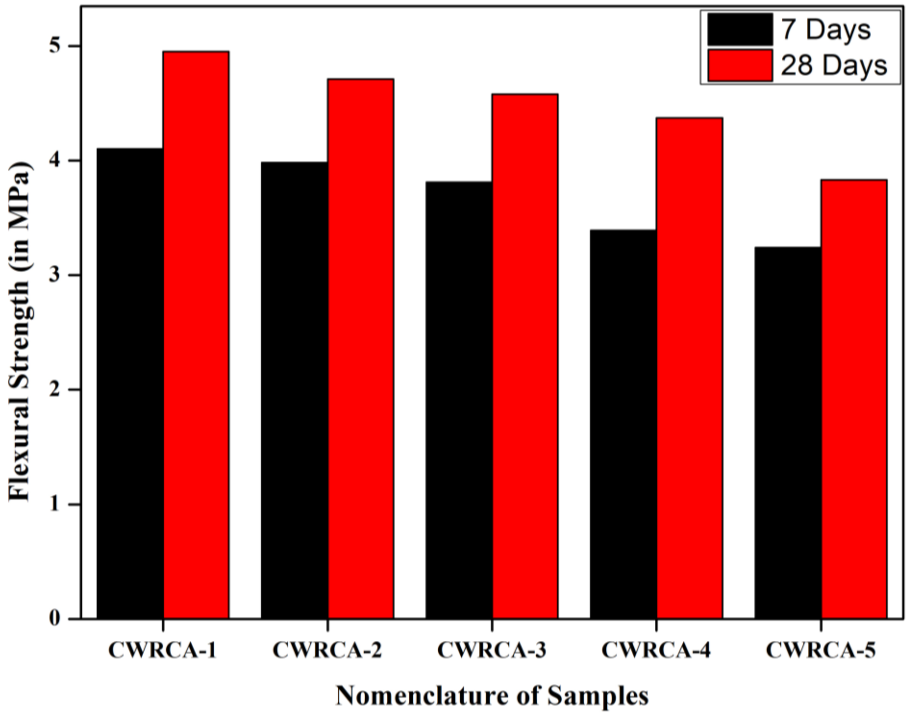

Fig.5- Flexural strength of concrete with RCA.

Scanning Electron Microscopy Analysis

The microstructure of Recycled Aggregate Concrete presents a complex and distinctive arrangement, particularly in the interfacial transition zone (ITZ) which significantly influences its mechanical performance. It consists of two distinct ITZs, namely a new ITZ located between the recycled aggregate (RA) and the new matrix, and an old ITZ situated between the RA and the previously adhered mortar. The ITZ serves as a critical determinant of strength, acting as a barrier to load transfer, and initiating crack formation in its vicinity. Typically, its thickness, shaped by hydration degree and RA mortar content, ranges up to 50 µm in normal cement concrete, characterized by fewer un-hydrated particles, pronounced porosity, and increased concentrations of $Ca\ (OH)_2$ and ettringite. Observations from scanning electron microscope (SEM) analyses indicate that the ITZ of RAC comprises intricate intrinsic pores, cracks, and fissures, appearing granular and porous. Researchers have noted that the porous nature of the ITZ contributes to reduced elastic modulus and lower strength in this specific area relative to the surrounding mortar matrix. Additionally, it has been found that the presence of varying-sized pores and cracks within the RA hinders proper penetration of cement paste, leading to a weak bond between the old and new ITZ. The presence of fine flake-like and whisker-like crystals in the voids further exacerbates the porous structure of the ITZ, contributing to the inferior strength properties of RAC compared to natural aggregate concrete. Microhardness testing has demonstrated that the strength characteristics of both ITZs are contingent on the water-to-cement (w/c) ratio, with the interface between the RA and the new mortar matrix exhibiting notably lower microhardness compared to other regions. The durability performance of RAC has been found to be directly linked to its porous microstructure, driven by its high absorption capacity and the loosely attached old mortar in the ITZ. Measures to enhance the porous nature have been a key focus to improve the strength and durability properties of RAC, as accessible porosity increases with both the increase in the w/c ratio of the concrete and the replacement level of RA. Fig 6 displays the magnification of mortar at 0.5µm, 01µm, 2µm and 10µm respectively.

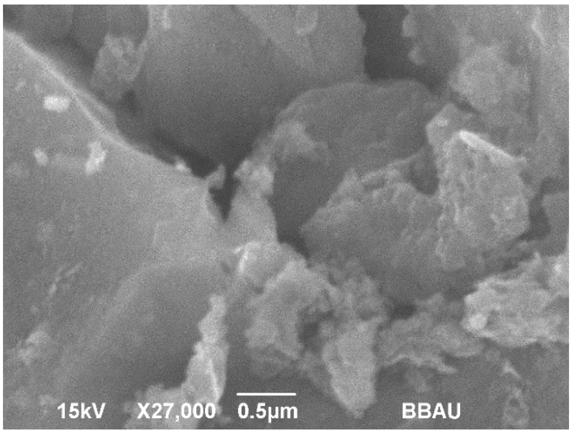

Fig 6- Morphology of mortar at 0.5µm magnification

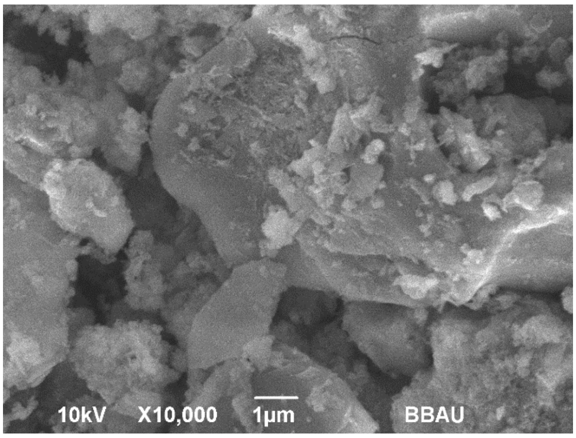

Fig 7- Morphology of mortar at 1µm magnification

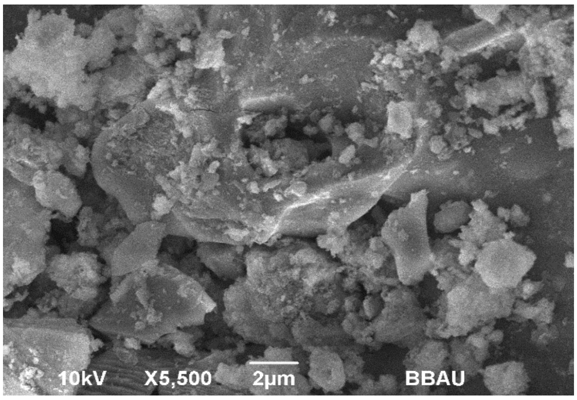

Fig 8- Morphology of mortar at 2µm magnification

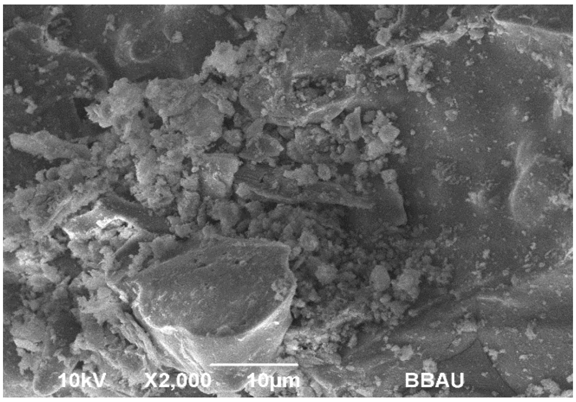

Fig 9- Morphology of mortar at 10µm magnification

IV. CONCLUSION

- Concrete incorporating up to 50% replacement of natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) exhibited a reduction in compressive strength ranging from 5% to 18% compared to standard M30 grade concrete. Substituting up to 100% of NCA with RCA led to a substantial decrease in strength, with a range of 20% to 45%, rendering it unsuitable for construction projects.
- Regarding the tensile strength, the inclusion of RCA up to 50% resulted in an 8% to 23% decrease in strength. Furthermore, an increase in RCA content led to a sharper decline of 23% to 48% in strength.
- The flexural strength of concrete beams containing up to 50% replacement exhibited a slight decline of approximately 2% to 8%. Samples with 100% replacement showed a decline of 11% to 23% compared to conventional M30 grade concrete.
- Laboratory findings suggest that concrete formulated with the substitution of NCA by RCA witnessed a decline in strength, yet a replacement level of up to 50% showed a minor reduction, with results surpassing the target mean strength, indicating its viability for construction purposes. However, any further increase in RCA content led to a significant decline, making the obtained results unsuitable for construction purposes.

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